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Methyl iodide and forced aeration on the post-harvest quality of lemons

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Abstract

Methyl iodide (MI) fumigation to control California red scale (*Aonidiella aurantii*) at dosages of 24, 28, and 32 g/m^3 for 2 h combined with 2- and 24-h forced aeration using 3.5 l of air per min at 21EC immediately after fumigation was tested on early-, mid- and, late-season lemons [*Citrus limon* (L.) Burm. F] from the coastal and desert regions. The MI treatment lowered fruit quality due to moderate to severe rind injury with increasing MI dosage. The degree of lemon phytotoxicity was influenced by season of harvest. Early season lemons of both coastal (cooler) and desert (warmer) regions sustained less fruit phytotoxicity than mid- and late-season lemons. Forced aeration of 24-h immediately after the MI treatment dramatically reduced fruit phytotoxicity irregardless of seasonal and climatic factors. Based upon the results of MI and on the known response of California red scale to this fumigant, we propose that a MI dosage of 26 g/m^3 for 2 h combined with 24-h forced aeration post-fumigation could provide an effective quarantine treatment for lemon.
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Keywords: Quarantine; Fumigant; Phytotoxicity; Seasonal effect

1. Introduction

It is critical in international trade that destructive pests are excluded or prevented entry into uninfested production areas. Thus, regulatory quarantine procedures have been developed to exclude or eradicate unwanted pests, and some of the adopted procedures have become common practice in world commerce (Smith et al., 1933; Kahn, 1989). In implementing quarantine regulations, oftentimes fumigants are required for disinfesting fruit commodities. Until recently, methyl bromide (MB) was the universal fumigant of choice, but has since become a prime target compound for phase-out because it is a significant stratospheric ozone depletor (Thomas, 1996).

Methyl halides such as MB and methyl iodide (MI) are found naturally in the atmosphere especially in coastal regions where certain flora favor their production (Li et al., 2001). Among these, MI is rapidly photo-decomposed by UV-light and persists only for a few days. In comparison, MB persists in the environment with a lifetime of 0.7–1.0 year. Thus, although MI is highly reactive and possesses similar lethality for organisms, it lacks the undesirable property of strato-

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spheric ozone destruction caused by MB. Lindgren (1938) first showed MI was efficacious against several insect species without apparent injury to plants. Later, in preplant application, MI was found effective in controlling certain plant diseases (Ohr et al., 1996). Also, under post-harvest conditions, MI used at a rate of 16 g/m^3 for 2 h was non-injurious to a number of fresh fruit commodities, but MI dosage of 32 g/m^3 for 4 h caused severe injuries (Claypool and Vines, 1956). Aung et al. (2001) used MI at 20 g/m^3 for 2 h on late-season coastal lemons for disinfesting California red scale, but the fruit sustained unacceptable surface rind injury. However, when MI fumigation of the lemon fruit was immediately followed by a forced aeration of 3.5 l of air per min at 21EC for 24 h, fruit phytotoxicity was greatly reduced. In light of this observation, we investigated further the effects of several MI dosages and forced aeration on the post-harvest quality/phytotoxicity of early-, mid- and, late-season lemons from two climatic regions.

2. Materials and methods

2.1. Sources of lemon fruit

Lemons, *Citrus limon* (L.) Burm. F., from the coastal region of Ventura, California and desert region of Yuma, Arizona were obtained during the early-, mid- and, late-season harvests. The harvested fruit were commercially graded, washed, shipping wax applied, and packed. Fruit maturity color index was measured with Minolta CR-300 chroma meter (Minolta, Ramsey, NJ) using the L^*, a^*, b^* color coordinates and calculated chroma and hue values. The seasonal dates and fruit maturity colour of the experimental lemons from the two climatic regions are summarized in Table 1.

2.2. Methyl iodide fumigation and forced aeration

The MI fumigation with immediate post-fumigation forced aeration of the lemons were similar to the reported procedure (Aung et al., 2001). Essentially, MI (Aldrich, St. Louis, MO, USA) was obtained as a colorless liquid with a boiling point of 42EC and stabilized with toluene. For fumigation, MI at 24, 28, and 32 g/m^3 was used in 28.3-l chambers consisting of a 50% load comprised of 55 fruit in cheesecloth bags (simulating bulk fumigation) held for 2 h at 21EC under normal atmospheric pressure. Following fumigation, the chambers were forced aerated using 3.5 l of air per min at 21EC for 24 h. After the treatments, the lemons were held in environmental rooms at 5EC and 85% relative humidity for specified periods before quality/phytotoxicity evaluation.

2.3. Fruit quality/phytotoxicity evaluation

The lemons were evaluated after the 1st and 3rd week of storage at 5EC for rind pitting or staining which developed after MI fumigation (Plate 1). Each fruit was visually rated using a scale of: healthy: sound quality commercial, blemish-free fruit; slight: very

Table 1
The seasonal date and fruit maturity color indices of coastal and desert lemons; notation L^* is brightness; a^* and b^* are chromaticity coordinates

Climatic region	Color notation				
	L^*	a^*	b^*	Chroma	Hue (°)
Coast					
Early (February 2002)	79.28	−6.72	62.92	63.3	96.1
Mid (June 2002)	75.64	−5.37	63.88	64.1	94.8
Late (September 2002)	76.88	−5.62	62.34	62.6	95.2
Desert					
Early (October 2002)	78.12	−5.99	51.44	51.8	96.6
Mid (November 2002)	77.43	−4.86	59.44	59.6	94.7
Late (January 2003)	77.52	−4.33	63.49	63.6	93.9

A smaller a^* value indicates a greener color, and a larger b^* value indicates a more yellow color; chroma was calculated using $\sqrt{(a^*)^2 + (b^*)^2}$, and Hue using Arctangent (b^*/a^*) in degrees; a hue angle of 90E is yellow and 180E is bluish-green.

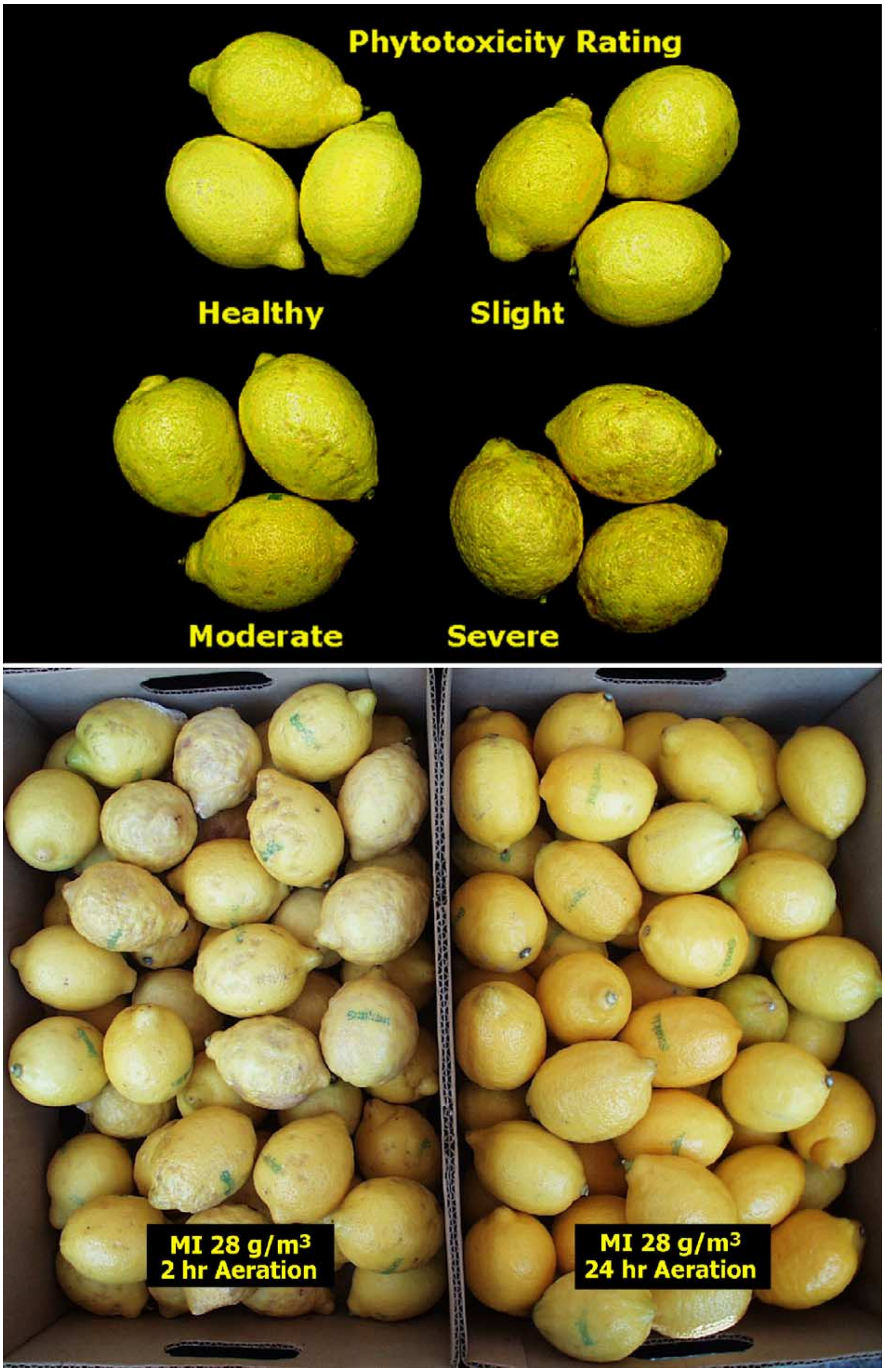

Plate 1. Photographs showing the phytotoxicity rating of lemon fruit, and the comparison of 28 g/m^3 methyl iodide fumigated fruit forced aerated for 2 h vs. 24 h; note the severe fruit injury of the 2-h aeration in contrast to the maintenance of fruit quality with the 24-h aeration treatment.

mild pitting or staining, with injury covering 1–5% of the flavedo (pigmented) surface area but would not affect marketability of the fruit; moderate: injury more pronounced and larger lesions covering 25% of the flavedo. These fruit may still be saleable but less attractive; severe: fruit with darkened areas and staining of the flavedo exhibiting a scalded appearance over >25% of the flavedo area and making the fruit unmarketable. The phytotoxicity (%) was calculated as: cumulated injured fruit number divided by total fruit number times 100 (Aung et al., 2001).

2.4. Experimental design and data analysis

The fumigation tests consisted of four treatments of three replication using a randomized complete block design. Each treatment (or chamber) contained 55 fruits. Analysis of variance procedure was used to analyze the data and a least significant difference (LSD) test at probability of $P = 0.05$ or $P = 0.01$ was used for comparing/determining the significance of treatment means. All percentage values were transformed using arcsin $\sqrt{\text{percentage}}$ transformation before analysis of variance and regression analysis.

3. Results and discussion

MI fumigation at dosages of 24, 28, and 32 g/m^3 caused moderate to severe rind injury (phytotoxicity) of lemon fruit obtained from the cold coastal and warm desert regions (Plate 1; Figs. 1 and 2). Lemons harvested in the later seasons sustained greater amount of fruit phytotoxicity. Thus, both early season coastal or desert fruit showed less phytotoxicity than mid- and late-season fruit. The early coastal lemons showed the least amount of fruit phytotoxicity due to MI fumigation at the dosages used. The MI injury to late season lemon fruit was maximal after 1-week storage at 5EC, whereas early season lemons showed moderate amount of phytotoxicity after storage of 1 week and followed by greater incremental injury after 3-week storage at 5EC. In contrast, forced aeration with 3.5 l of air per min at 21EC for 24 h immediately after MI fumigation significantly (>$P = 0.01$) reduced fruit phytotoxicity irregardless of both season and climatic region from which the lemons were obtained.

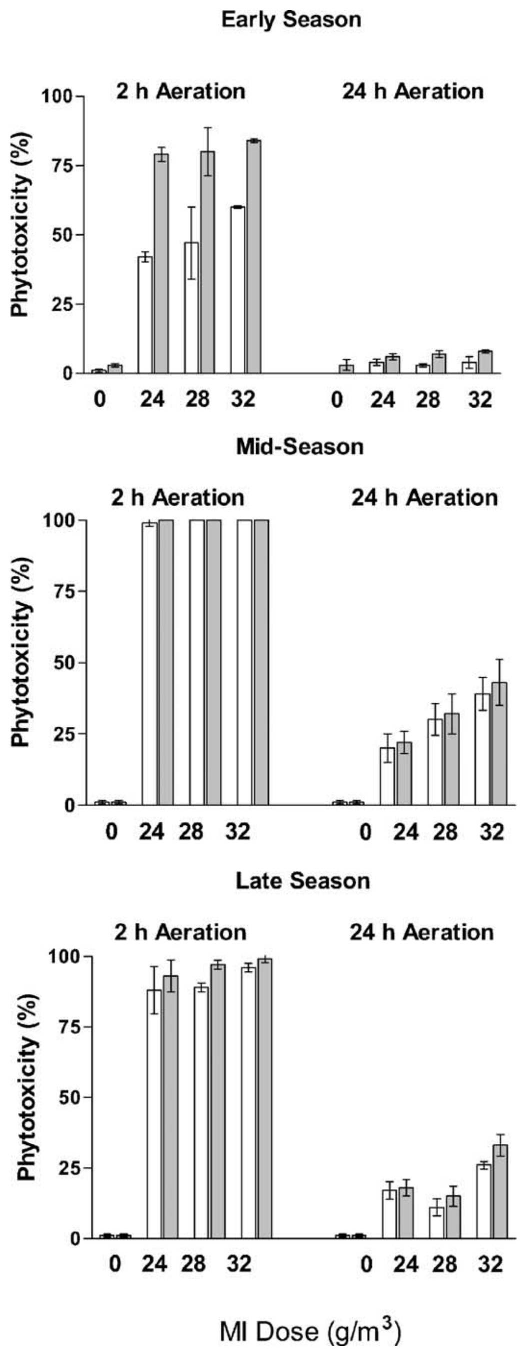

Fig. 1. Effects of methyl iodide fumigation and post-fumigation forced aeration on the quality of early-, mid- and, late-season coastal lemons. Fruit injury is denoted by □ after 1 week of storage at 5 °C, and ■ denotes fruit injury after 3 weeks of storage at 5 °C; ± values denote standard error; MI dose is in g/m^3.

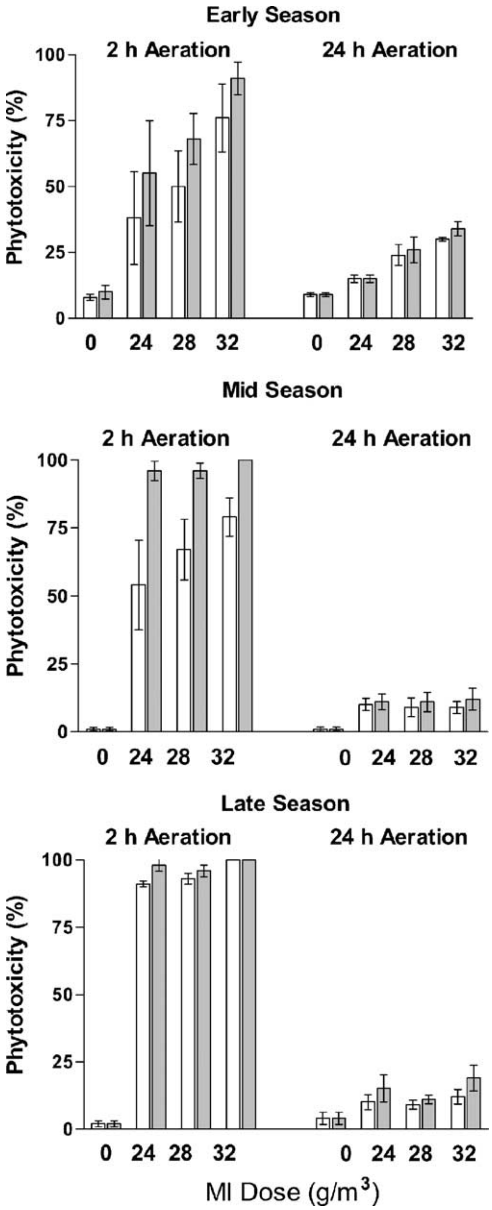

Fig. 2. Effects of methyl iodide fumigation and post-fumigation forced aeration on the quality of early-, mid- and, late-season desert lemons. Fruit injury is denoted by □ after 1 week of storage at 5 °C, and ■ denotes fruit injury after 3 weeks of storage at 5 °C; ± values denote standard error; MI dose is in g/m^3.

Forced aeration of 24 h immediately after MI fumigation dramatically lessened lemon fruit phytotoxicity (Plate 1), but the mechanism of injury reduction is not known. It appears likely, however, that the forced aeration rapidly desorbed or removed the toxic fumigant in the vicinity of the fruit and reduced the contact time of the flavedo tissues with the fumigant. Although the MI or its reaction products which impact and cause flavedo phytotoxicity remains unknown, it may be inferred from the property of iodine chemistry that some of the reactive chemical species of MI which include CH_3^+, I^+, I_2^+, IO^C, CH_2I, (Choi et al., 1999; Mcfiggans et al., 2000; Vogt et al., 1999) may be relevant. However, the significance of their role(s) on fruit tissue injury needs to be determined.

An acceptable fumigant for post-harvest use must have a low economic threshold (i.e. low level of fruit phytotoxicity) and be efficacious against a quarantine pest. For MI, an earlier study indicated that an efficacious dosage for lemons was between 20 and 40 g/m^3 (Aung et al., 2001) whereas in the present work (Figs. 1 and 2), the effective dosage without severe fruit injury was less than 28 g/m^3 for 2 h. The dosages used in this study were based upon studies conducted previously on the tolerance of California red scale and diapausing larvae and egg stages of the codling moth, *Cydia pomonella*, to methyl iodide (Aung et al., 2001; Leesch and Zettler, 2000; and Zettler et al., 2001). These dosages would most probably be the ones used for citrus or stonefruit in the future. Based upon the results, we concluded that the optimal MI rate for lemons is about 26 g/m^3 for 2 h. This MI rate is approximately 25% less than equivalent MB quarantine dosage used on lemons (Forney et al., 1991) and other fruit commodity (Harvey and Harris, 1982). The lesser MI dosage is due to slightly greater potency/reactivity and reflects its different chemical property among the halides.

It is well recognized that lemon fruit morphology and chemical composition are altered and determined by both season of harvest and growing regions (Sinclair, 1984; Turrell et al., 1964). However, it is unclear how the physical and chemical characteristics of the lemons influence the fruit resistance or susceptibility to injury from regulatory quarantine fumigation treatment (Aung et al., 1999). Thus, as shown in Figs. 1 and 2, both early season coastal and desert fruit were less injured by MI fumigation than mid- and late-season fruit. It is conceivable that fruit developing earlier in the season are subjected to lesser increasing temperature and nutrient stresses than later season fruit. Experience has shown that fruit obtained as the season advances were more prone to injury. The underlying cause(s) of the differential lemon fruit behavior to fumigant injury remains unknown.

The efficacy of MI for post-harvest pest disinfestation has been recognized (Claypool and Vines, 1956; Aung et al., 2001), but the MI-induced injury causing fruit quality reduction diminishes its usefulness. In lemons, the use of forced aeration treatment immediately following MI fumigation has effectively and consistently reduced fruit phytotoxicity. This approach provides a promising alternative to MB quarantine treatment. There are presently no known MB-alternative fumigants for post-harvest fresh fruit disinfestation which are efficacious without causing varying degrees of injury to fruit. Thus, the MI fumigation combined with post-fumigation forced aeration offers a potential efficacious treatment with minimum fruit phytotoxicity. In light of these results, the use of MI on other fresh fruit commodities needs to be tested. Although MI is not registered for commercial use, its registration is under active consideration (Allan and Platt, 2002).

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